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Tissue analysis technology for nitrogen fertilization of potato grown under subtropics short day conditions

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Abstract

Field experiments were conducted for three crop seasons to develop tissue analysis technology for optimizing N fertilization in potato grown under short day conditions in subtropics. Nitrogen deficiencies could be detected as early as 25 days after planting (DAP) by tissue analysis of NO_3-N concentration in petioles. Petiolar NO_3-N declined sharply with age of the crop from 25 to 60 DAP and was significantly correlated at all stages of growth with applied N and tuber yield of potato. Critical concentrations of Petiolar NO_3-N were 1.28, 1.23, 1.07 and 0.96% in an early maturing cv. Kufri Chandramukhi and 2.16, 1.95, 1.40 and 1.18% in a late maturing cv. Kufri Badshah at 25, 40, 50 and 60 DAP, respectively. Optimum yields were obtained when petiolar NO_3-N was maintained above critical concentrations through the growth period up to 60 DAP by corrective side dressing of N. Response to corrective side dressing of N decreased with increasing concentration of petiolar NO_3-N. Optimum rate of N for side dressing up to 30 DAP was 142, 116, 90, 64 and 37 kg ha^{-1} for petiolar NO_3-N of 0.5, 1.0, 1.5, 2.0 and 2.5%, respectively in Kufri Chandramukhi. Corresponding rates of side dressed N were 183, 164, 146, 127, 108 kg ha^{-1} in late maturing cv. Kufri Badshah. For optimum yields, fertilization of 80 to 120 kg N ha^{-1} at the time of planting followed by corrective side dressing as recommended by petiolar tissue analysis is advocated.

Introduction

Estimating fertilizer requirement of crops as accurately as possible through soil and plant tests is basic to efficient fertilizer management. Excessive and suboptimal N supply in plant tissue decrease the tuber yield of potato and leads to inefficient use of N fertilizers (Singh, 1991). Nitrogen needs of the potato crop during the growing season can be assessed by tissue analysis (Sharma, et al., 1991; Singh, 1991). Information is severely lacking on tissue analysis for N fertilizer management in potato grown under short day conditions. Potato is grown under short day conditions in vast area in Indian sub continent, parts of China and United States of America 29°–30°N. An experiment was, therefore, conducted to develop tissue analysis technology for optimizing N fertilization in potato crop grown in subtropics south of 31°N under short day conditions.

Materials and methods

Field experiments were conducted from 1985 to 1988 at Central Potato Research Station, Jalandhar, (31°N latitude and 75°E longitude, 237 m above mean sea level). The soil of the experimental site is a Typic Ustochrept with loamy sand texture, pH 7.5, organic carbon 0.25%, C.E.C. 3.2 c mol(P^+) kg^{-1}, E.C. 0.099 dS m^{-1} and available N-P-K as 188-25-137 kg ha^{-1}. Treatments consisted of combinations of 4 rates of N (0, 50, 100, 150 kg ha^{-1}) applied at planting to provide different concentrations of N in tissues, over which 4 rates of side dressed N (0, 50, 100, 150 kg ha^{-1}) were imposed at 30 days after planting. The treatments were replicated 4 times in a randomized block design. Each plot was 6 m × 2 m (10 rows of 10 tubers each). All plots were uniformly fertilized with single super phosphate (44 kg P ha^{-1}) and muriate of potash (84 kg K ha^{-1}) at planting. Ammonium sulphate was used as the N-source. Potato was planted in the 1st week of Oct. and harvested at full maturity in Jan. The experiment was conducted for two years each with an early (80–90 days) and late (110–120 days) maturing cultivar Kufri Chandramukhi (1985–86 and 1987–88) and Kufri Badshah (1986–87 and 1987–88), respectively. Both cultivars produce high yields. Separate experiments were conducted with each cultivar. The crops were optimally irrigated, manually weeded and normal plant protection measures were taken.

From each plot, 30 to 35 petioles of 4th leaf from top of the shoot were sampled at 25, 40, 50 and 60 days after planting. Fresh petioles (5 g) were macerated thoroughly in 2% acetic acid and filtered. Nitrate-N was analysed in the extract colourimetrically (Singh, 1988). Dry matter in petioles was also recorded separately to express the NO_3-N concentration on dry weight basis, by drying the samples in oven at 60°C to a constant weight. Mean dry matter in petioles was 5%, which remained unaffected by the age of the plants or the treatments up to 60 days after planting.

Data on tuber yield and NO_3-N concentration in petioles was statistically analysed and pooled after applying Bartlett's test for homogeneity of variances (Panse and Sukhatme, 1967). Economic optima of side dressed N for different concentrations of petiolar NO_3-N was calculated from the quadratic equations using the formula (Cooke, 1972):

$$x = \frac{1}{2c}(q/p - b)$$

where, x = optimum rate of side dressed N (kg ha^{-1}), q = price of N (Rs. 15 kg^{-1}), p = selling price of potato (Rs. 75/q), b and c are the coefficients of response equations.

Results and discussion

Applied nitrogen and petiolar nitrate

Increasing rates of N applied at planting (basal) linearly increased the NO_3-N concentration in petioles of both potato cultivars (Table 1 and 2). The basal N rates of 0, 50, 100 and 150 kg ha^{-1} led to petiolar NO_3-N concentrations of 0.48, 1.22, 1.53 and 2.26%, respectively, in cv. Kufri Chandramukhi 25 days after planting (Table 1). Corresponding concentrations of NO_3-N in cv. Kufri Badshah was 0.64, 1.47, 2.34 and 2.98% (Table 2). When 0 N was side dressed at 30 days after planting (DAP), the NO_3-N decreased up to 60 DAP (Table 1 and 2) and lowest tuber yield was recorded at each rate of basal N with both the cultivars (Fig. 2). Increasing rates of side dressed N could maintain higher levels of NO_3-N in petioles up to 60 DAP. However, in each treatment petiolar NO_3-N decreased from 40 to 60 DAP.

Petiolar NO_3-N was highly correlated with applied N (Table 3). However, at the early stage of growth 25 DAP the correlation ($r = 0.99^{**}$) was higher with basal N, while at later stages (40 to 60 DAP) the correlation ($r = 0.88^{**}$ to 0.98^{**}) was higher with total N applied. Because rates of side dressed N were applied at 30 DAP, the petiolar NO_3-N at early stage of growth was likely to be more correlated with the basal N applied.

Nitrate-N concentration in plant is roughly in proportion to available N in soil (Chapman, 1971) and is closely correlated with N applied (Singh, 1991). Nitrate-N tend to be higher in petioles of young plants (4 to 6 weeks) and then decrease rapidly as plants mature (Singh, 1991).

Petiolar nitrate and tuber yield of potato

Petiole NO_3-N was significantly correlated with tuber yield of potato through the crop growth period (Table 4). However, the degree of corre-

Table 1. Main effects of nitrogen rate applied at planting (Basal) and side dressed 30 days after planting on NO_3-N concentration in petioles and tuber yield of potato cv. Kufri Chandramukhi

Nitrogen (kg ha^{-1})	Petiolar NO_3-N (%DM)[b] days after planting				Tuber yield (q ha^{-1})		
	25[a]	40	50	60	1985–86	1987–88	Mean[b]
Basal N							
0	0.48	1.03	0.74	0.56	201	165	182
50	1.22	1.46	0.81	0.68	247	253	250
100	1.53	1.56	1.24	1.11	258	297	277
150	2.26	2.10	1.59	1.48	253	307	280
L	0.56**	0.33**	0.30**	0.32**	NS	NS	NS
Q	NS	NS	NS	NS	−12.7**	−19.5**	−16.2**
Side dressed N[a]							
0		0.81	0.53	0.44	219	224	221
50		1.41	0.74	0.60	237	251	243
100		1.79	1.39	1.24	254	268	261
150		2.15	1.73	1.55	249	279	264
L		0.44**	0.42**	0.40**	NS	18.2*	14.7*
Q		NS	NS	NS	−5.7**	−4.0**	−4.7**

[a] Side dressing N was applied 30 days after planting;
[b] pooled mean of two crop seasons;
DM: Dry matter;
L and Q denote linear and quadratic responses, respectively, to applied N; NS = not significant; * = significant (0.05 *p*); ** = significant (0.01 *p*).

Table 2. Main effects of nitrogen rate applied at planting (Basal) and side dressed 30 days after planting on NO_3-N concentration in petioles and tuber yield of potato cv. Kufri Badshah

Nitrogen (kg ha^{-1})	Petiolar NO_3-N (%DM)[b] days after planting				Tuber yield (q ha^{-1})		
	25[a]	40	50	60	1986–87	1987–88	Mean[b]
Basal N							
0	0.64	1.52	0.86	0.65	268	150	209
50	1.47	1.58	1.01	0.90	376	287	330
100	2.34	1.89	1.31	1.26	429	365	397
150	2.98	2.12	1.63	1.55	476	401	438
L	0.79**	0.21**	0.26**	0.31**	67.7*	83.4*	75.4*
Q	NS	NS	NS	NS	−15.2*	−24.5**	−20.0**
Side dressed N[a]							
0		1.07	0.76	0.62	293	245	269
50		1.64	1.02	0.91	373	296	334
100		2.11	1.41	1.24	433	328	380
150		2.29	1.61	1.58	449	331	390
L		0.41**	0.29**	0.32**	52.8*	NS	40.9*
Q		NS	NS	NS	−16.0**	−12.0**	−13.7**

[a] Side dressing N was applied 30 days after planting;
[b] pooled mean of two crop seasons;
DM: Dry matter;
L and Q denote linear and quadratic responses, respectively, to applied N; NS = not significant; * = significant (0.05 *p*); ** = significant (0.01 *p*).

Table 3. Correlation of petiolar NO_3-N concentration with rates of N applied at planting (Basal) and total (Basal + side dressed) N applied

Cultivar	Applied N	Stages of growth (days after planting)			
		25	40	50	60
		Correlation (r)			
Kufri-	Basal	0.99**	0.58**	0.53*	0.55*
Chandramukhi	Total	0.70**	0.94**	0.91**	0.88**
Kufri-	Basal	0.99**	0.43^{NS}	0.65**	0.67**
Badshah	Total	0.71**	0.90**	0.98**	0.97**

NS = not significant; * = significant (0.05 *p*); ** = significant (0.01 *p*).

lation decreased with age of the crop in the early maturing cv. Kufri Chandramukhi. This may indicate a less efficient utilization of side dressed N. In the late maturing cv. Kufri Badshah a high degree of correlation even later in the growth period indicated an efficient utilization of side dressed N. Late maturing cultivars utilize applied N more efficiently than early maturing ones (Sharma, 1990; Upadhayay and Sharma, 1987). These results about effect of age of plant and cultivars on correlation between petiole NO_3-N and tuber yield suggest for careful sampling under field conditions to obtain best results from tissue analysis for optimizing N fertilization to potato.

High degree of correlation between petiole NO_3-N and applied N (Table 3) on one hand and tuber yield (Table 4) on the other hand at 25 DAP indicated that N supply at early stage of growth of potato was critical and deficiency could be detected as early as 25 days after planting. Tuber initiation stage (25 to 30 DAP) was reported to be critical to nutrient stress in potato grown under short day conditions in the plains of Indian sub continent (Sharma et al., 1991).

Table 4. Correlation of petiolar NO_3-N concentration with tuber yield of potato

Stages of growth (days after planting)	Cultivars	
	Kufri Chandramukhi	Kufri Badshah
	Correlation (r)	
25	0.82**	0.83**
40	0.77**	0.79**
50	0.61*	0.85**
60	0.60*	0.85**

* = significant (0.05 *p*); ** = significant (0.01 *p*).

Sufficiency/deficiency levels of petiolar NO_3-N concentration

Best fit regressions of tuber yield and petiole NO_3-N at different stages of growth were calculated (Table 5). At each growth stage except 25 DAP, the quadratic equation provided a higher value of coefficient of determination (R^2) than the linear equation. From these equations the critical concentrations and relative ranges of sufficiency/deficiency based on predicted yields were calculated. Concentrations associated with yield reduction of 0 to 10, 10 to 20, 20 to 40 and more than 40% from the maximum yield was denoted as range of sufficiency, slight deficiency, moderate deficiency and extreme deficiency, respectively (Engel and Zubriski, 1982). While critical concentration corresponded to 10% reduction in yield from the maximum (Ulrich and Hills, 1973). Different ranges and critical concentrations thus obtained are presented in Table 6. The critical concentrations of petiole NO_3-N at 25, 40, 50 and 60 days after planting were 1.28, 1.23, 1.07, and 0.96% respectively, for Kurfi Chandramukhi. Corresponding critical concentrations for Kufri Badshah were 2.16, 1.95, 1.41 and 1.18%. The petiole NO_3-N concentrations associated with 100, 90 and 60% of the maximum yield were found to decrease linearly with age of the crop (Fig. 1). From Figure 1 it was possible to identify the NO_3-N concentration associated with relative levels of deficiency/sufficiency through the crop growth period up to 60 DAP. Critical concentration of NO_3-N for late maturing cv. Kufri Badshah was 22 to 69% more than the early maturing cv. Kufri Chandramukhi at different stages of growth (Table 6). This could be due to higher

Table 5. Regression of tuber yield of potato (q ha^{-1}) on petiolar NO_3-N concentration at different stages of growth

Stages of growth (days)	Regression equation	Constants of regression equation ($Y = a + bx + cx^2$)			R^2
		a	b	c	
		Kufri Chandramukhi			
25	L	167.55	59.39	–	0.66**
	Q	112.44	162.32	−37.59	0.76**
40	L	164.41	54.97	–	0.59**
	Q	125.30	160.51	−38.09	0.63**
50	L	199.34	45.31	–	0.37*
	Q	138.81	163.12	−42.99	0.47*
60	L	207.57	43.33	–	0.36*
	Q	147.48	177.45	−51.44	0.48*
		Kufri Badshah			
25	L	166.77	93.70	–	0.69**
	Q	93.05	201.39	−29.85	0.72**
40	L	87.80	142.44	–	0.62**
	Q	−35.46	324.38	−57.83	0.64**
50	L	111.10	191.42	–	0.73**
	Q	−45.78	486.28	−120.26	0.78**
60	L	162.00	164.52	–	0.72**
	Q	−3.12	515.07	−149.48	0.82**

L and Q denote linear and quadratic equations, respectively; * = significant (0.05 *p*); ** = significant (0.01 *p*).

Table 6. Sufficiency/deficiency ranges and critical NO_3-N (%) concentration in petioles at various stages of growth in two potato cultivars

Stages of growth (days)	Sufficiency	Slight defi.	Moderate defi.	Extreme defi.	Critical conc.
	Kufri Chandramukhi				
25	2.16–1.28	1.28–0.92	0.92–0.41	<0.41	1.28
40	2.11–1.23	1.23–0.86	0.86–0.35	<0.35	1.23
50	1.90–1.07	1.07–0.73	0.73–0.24	<0.24	1.07
60	1.72–0.96	0.96–0.64	0.64–0.20	<0.20	0.96
	Kufri Badshah				
25	3.37–2.16	2.16–1.67	1.67–0.96	<0.96	2.16
40	2.80–1.95	1.95–1.60	1.60–1.10	<1.10	1.95
50	2.02–1.41	1.41–1.16	1.16–0.80	<0.80	1.41
60	1.72–1.18	1.18–0.96	0.96–0.64	<0.64	1.18

requirement of N by the more responsive, high yielding late maturing cv. Kufri Badshah. In India under short day conditions in a late maturing cultivar the critical concentration of NO_3-N in petioles was found to be 2.02 and 1.35% at 40 and 50–60 days after planting, respectively (Singh 1991).

Response to rate of nitrogen applied at planting

The purpose of applying N at planting (basal) in this experiment was to have various concentrations of NO_3-N in petioles over which rates of side dressed N were super imposed. However, the results showed the importance of the basal application. Mean response due to the main effect of rates of basal N of 50, 100 and 150 kg ha^{-1} was 68, 95 and 98 q ha^{-1}, respectively in early maturing cv. Kufri Chandramukhi (Table 1). Response due to main effect of rates of total (basal + side dressed) N of 50, 100, 150, 200, 250 and 300 kg ha^{-1} was 48, 98, 122, 143 and 139 q ha^{-1}, respectively, in cv. Kufri Chandramukhi. (Table 7). Similarly mean response

Table 7. Main effect of total (Basal + Side dressed) nitrogen applied on tuber yield of two potato cultivars

Main effect of total nitrogen applied (kg/ha)	Number of treatment combinations included	Tuber yield (q ha^{-1})[a]	
		Kufri Chandramukhi	Kufri Badshah
Levels of N			
0	1	139	110
50	2	187	205
100	3	237	304
150	4	261	362
200	3	282	424
250	2	282	441
300	1	278	453
L		23.3**	57.9**
Q		−6.1**	−9.7**

[a] Mean of two crop seasons;
L and Q denote linear and quadratic responses, respectively, to applied N; ** significant (0.01 p).

due to main effect of rates of basal N of 50, 100 and 150 kg ha^{-1} was 121, 189 and 230 q ha^{-1}, respectively, in late maturing cv. Kufri Badshah. Response due to main effect of total (basal + side dressed) N of 50, 100, 150, 200, 250 and 300 kg ha^{-1} was 95, 194, 252, 314, 331 and 343 q ha^{-1}, respectively, in cv. Kufri Badshah (Table 7). The mean response to basal N was more than the equivalent rates of side dressed N in both the cultivars (Table 1 and 2). The nature of response curves in Figure 2 shows that under suboptimal rates of basal N, any amount of side dressing of N would fail to maximize the tuber yield of potato. Therefore, the best strategy for efficient N fertilizer management would be to apply basal N of 80 to 100 kg ha^{-1} to early maturing cultivars and 100 to 120 kg ha^{-1} to late maturing ones, followed by side dressing of N as indicated by tissue analysis. The tissue analysis data gives the integrated N supply conditions both from native soil sources and that applied at planting. Split application of 1/2 to 2/3 of the N at planting and the rest at earthing up 30 days after planting maximizes the tuber yield of potato grown in plains of India, with only few exceptions (Sharma et al., 1991). The N needs of potato crop grown under short day conditions in Indo-Gangetic plains varied from 180 to 240 kg ha^{-1} (Sharma et al., 1991).

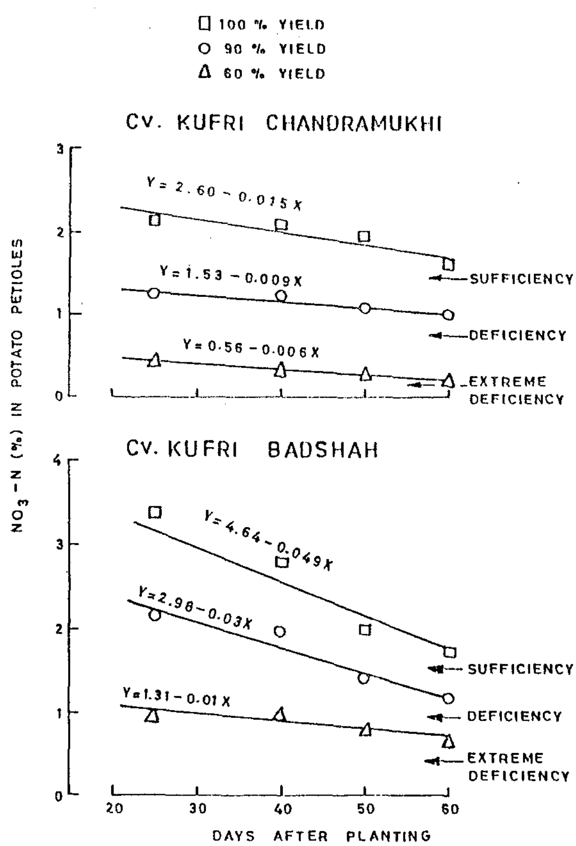

Fig. 1. Sufficiency/deficiency ranges of petiolar NO_3-N concentration in two potato cultivars as affected by days of growth after planting.

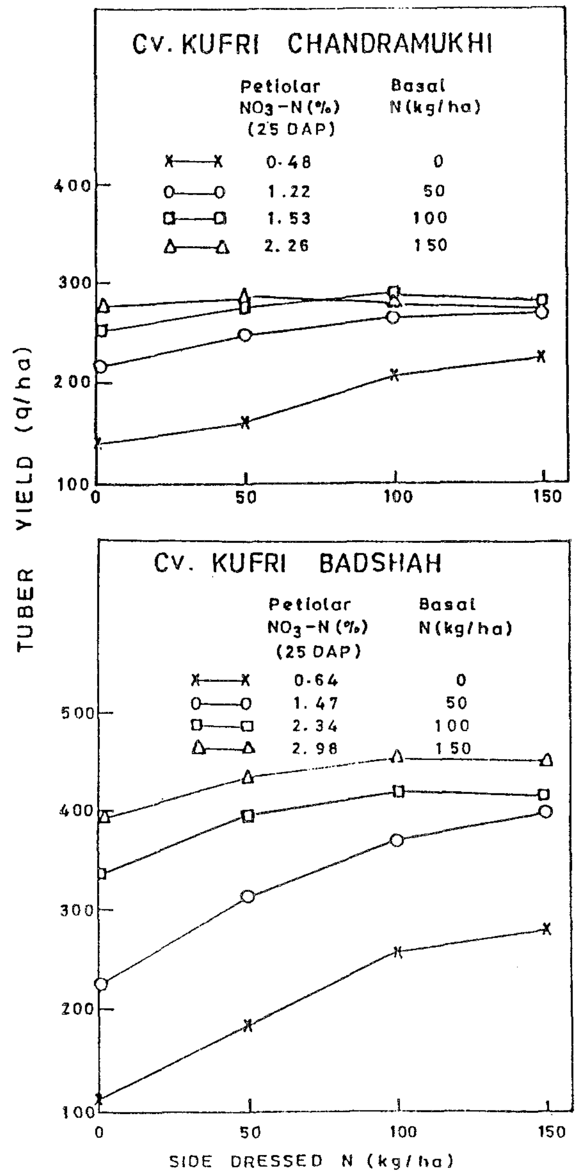

Fig. 2. Response to levels of side dressed N as affected by petiolar NO_3-N concentration in an early and late maturing cv. Kufri Chandramukhi and Kufri Badshah respectively.

Petiolar nitrate and response to side dressed nitrogen

Response to side dressed N at earthing up 30 days after planting varied depending upon the NO_3-N concentration in petioles in both the cultivars (Fig. 2). Higher concentration of NO_3-N in petioles reduced the response to side dressed N. Mean response to side dressed N of 50, 100 and 150 kg ha^{-1} was 22, 40 and 43 q ha^{-1}, respectively, in early maturing cv. Kufri Chandramukhi (Table 1). Corresponding response in late maturing cv. Kufri Badshah was 65, 111 and 121 q ha^{-1} (Table 2). Late maturing cv. Kufri Badshah responded more to rates of side dressed N due to longer duration of active green foliage and thus longer bulking period that resulted in higher tuber yields. Late maturing cultivars are more responsive to nitrogen application (Sharma, 1990; Upadhayay and Sharma, 1987). Differential response of potato cultivars to N is attributed to duration of the crop and genetical capacity to produce large size tubers (Sharma, 1990).

Petiolar nitrate and optimum rate of side dressed nitrogen

The optimum rate of side dressed N to Kufri Chandramukhi at earthing up 30 days after planting was 150, 103, 74 and 59 kg ha^{-1} for petiolar NO_3-N of 0.48, 1.22, 1.53 and 2.26%, respectively, at 25 DAP (Table 8). Similarly the optimum rate of side dressed N for Kufri Badshah was 169, 166, 101 and 93 kg ha^{-1} for petiolar NO_3-N concentration of 0.64, 1.47, 2.34 and 2.98%, respectively (Table 8). To recommend N for side dressing at earthing up based on petiolar NO_3-N contents, the best fit linear relationship between petiolar NO_3-N concentration at 25 DAP and corresponding optimum rate of side dressed N was worked out (Fig. 3). From these equations optimum rate of side dressed N at various concentrations of petiolar NO_3-N can be easily calculated. Optimum rate of side dressed N to early maturing cv. Kufri Chandramukhi was 142, 116, 90, 64 and 37 kg ha^{-1} for petiolar NO_3-N content of 0.5, 1.0, 1.5, 2.0 and 2.5%, respectively (Fig. 3). Corresponding rate of side dressed N to late maturing cv. Kufri Badshah was 183, 164, 146, 127 and 108 kg ha^{-1}. Optimum yields required side dressing of N even if petiolar NO_3-N was more than the critical concentration of 1.28 and 2.16% at 25 DAP in cultivars Kufri Chandramukhi and Kufri Bad-

Table 8. Optimum rate of nitrogen for side dressing in potato up to 30 days after planting (DAP) at different concentrations of NO_3-N in petioles

Petiolar NO_3-N at 25 DAP (%)	Constants of response equation $(Y = a + bx + cx^2)^d$ a	b	c	R^2	Optimum N (kg ha^{-1})	Likely response (q ha^{-1})
	Kufri Chandramukhi					
0.48	136.30	0.616	–	0.96	150[j]	92
1.22	217.4	0.738	−0.0026	0.99	103	48
1.53	253.9	0.719	−0.0035	0.99	74	34
2.26	270.9	0.698	−0.0042	0.72	59	26
	Kufri Badshah					
0.64	108.8	1.931	−0.0051	0.99	169	181
1.47	225.3	2.027	−0.0055	0.99	166	185
2.34	342.2	1.395	−0.0059	0.99	101	81
2.98	396.8	1.147	−0.0051	0.99	93	62

[d] Y = tuber yield of potato (q ha^{-1}) and x = side dressed N (kg ha^{-1});
[j] highest rate of side dressed N tried since response was linear.

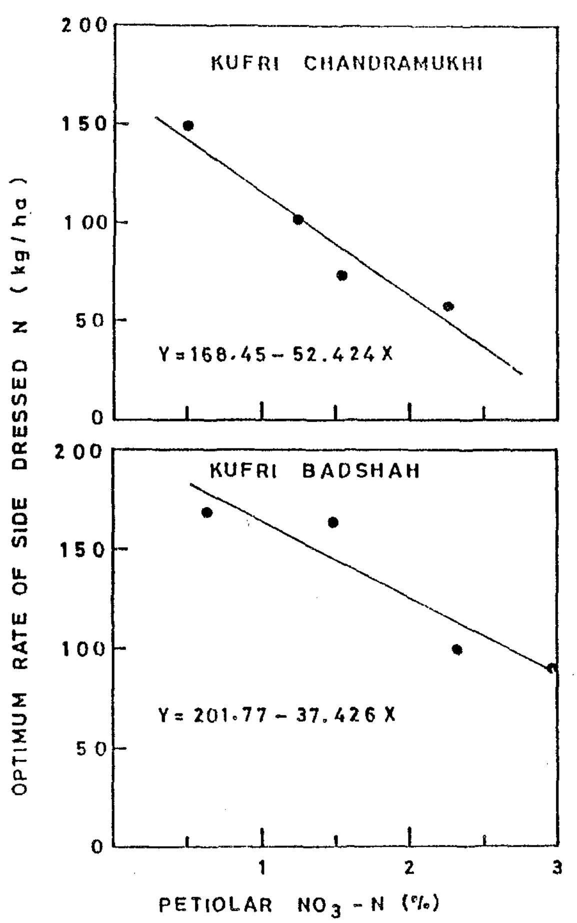

Fig. 3. Relationship between optimum rate of side dressed N (kg ha^{-1}) and petiolar NO_3-N concentration in two potato cultivars.

shah, respectively. The rapid decline in petiolar NO_3-N concentration with age of the crop explains the phenomenon (Table 1 and 2). Concentrations of petiolar NO_3-N higher than the critical limit at 25 DAP declined to less than the varying critical concentrations at 40 or 50 or 60 DAP in either absence or suboptimal rates of side dressed N. It follows that to obtain optimum yields the N supply has to be regulated in such a way as to maintain the concentration of petiolar NO_3-N above the varying critical concentrations through the crop growth period from 25 to 60 days after planting.

Data showed that side dressing N based on petiole NO_3-N concentration has the potential to optimize N fertilization of potato grown under short day conditions. Petiole NO_3-N enabled detection of deficiencies as early as 25 days after planting. Varietal differences in NO_3-N concentration in early and late maturing cultivars were wide enough to have separate recommendations.

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